A Little Modern Physics

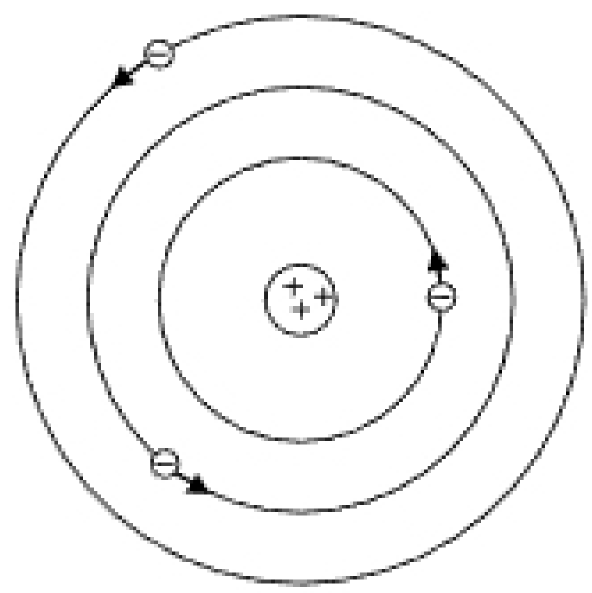
"Modern" physics means physics discovered after 1900; i.e. twentieth-century physics.

The late nineteenth century (roughly 1880 – 1900) was a time of blissful ignorance for physicists. Many physicists believed that Newton's mechanics and Maxwell's E&M could explain everything. Boy, were they wrong!

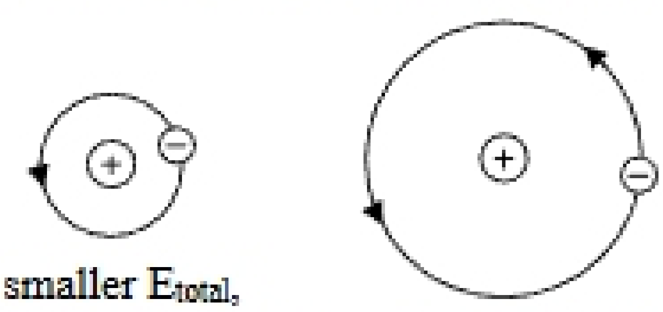
Three revolutions in our understanding of the physical world occurred in the 20th century:
1) Special Relativity, a theory of space and time (Einstein 1905)

2) General Relativity, a theory of gravity (Einstein, 1916)

3) Quantum Mechanics, a theory of the behavior of atoms (Planck, Einstein, Bohr, Heisenberg, Schrodinger, Born, Dirac, Pauli, …, 1900-1928)



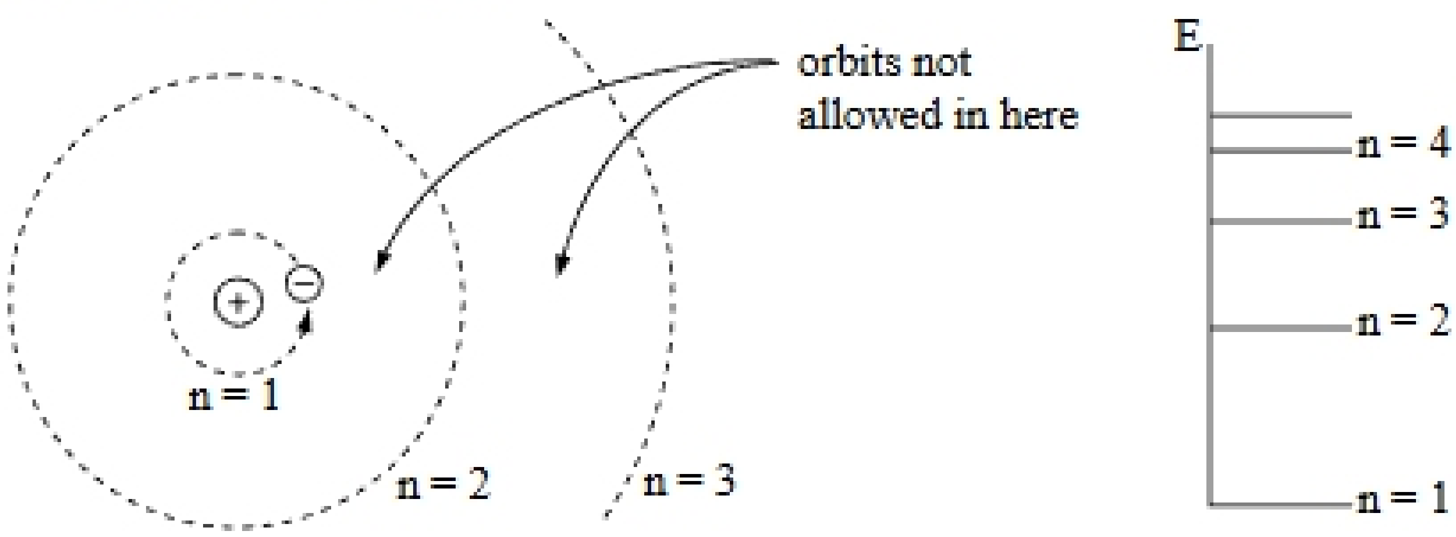
In 1911, Ernest Rutherford (New Zealand/Britain) did an experiment that showed that an atom consists of a small, heavy, positively-charged nucleus, surrounded by small light electrons. The electrons are held in orbit around the positive nucleus by the coulomb force (similar to a planet in orbit around the sun, held by the gravitational force). The electron has a total energy $E_{tot} = KE+PE$. Classical E&M and Newton's mechanics predicts that the electron can have any total energy. One can show that higher energy corresponds to a larger radius orbit with a longer period T (lower frequency $f = 1/T$).



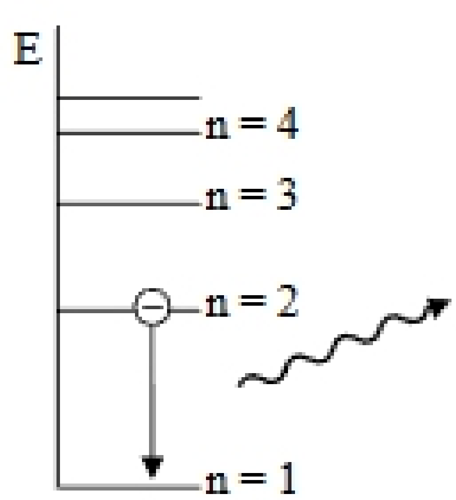
smaller E_{total}, higher frequency | larger E_{total}, lower frequency

But if the electron can have any total energy, it can orbit with any frequency. And the atom can then give off light of any frequency. (Recall that if a charges shakes with frequency f, it gives off light of that same frequency f.) However, this prediction conflicts with experiment. Experimentally, it is found that atoms only give off light at certain specific frequencies. Each element (H, He, C, N, O, etc) emits a pattern of light at particular frequencies. The pattern of frequencies give a unique fingerprint which can be used to identify the element producing the light.

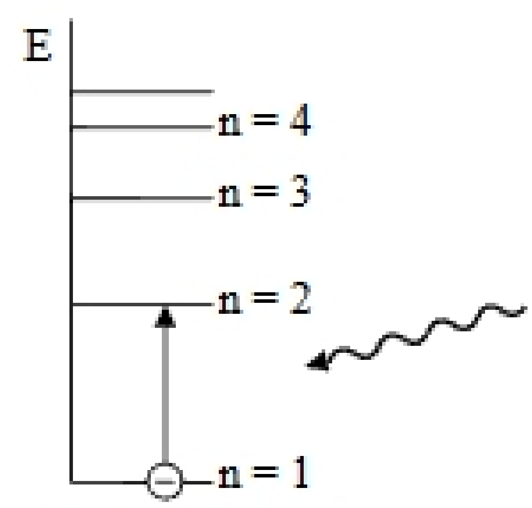
In the early 20th century (roughly 1918–1928), a new theory called **Quantum Mechanics,** was developed to explain the behavior of atoms. Quantum mechanics predicts that only certain electron energies are allowed in an atom. Classical mechanics predicts that any energy is possible, and so the allowed energies form a *continuum*; quantum mechanics predicts that only certain energies are allowed and so the energies are *quantized*, that is, discrete. The allowed energies are labeled with a *quantum number* n. The quantum number n = 1 is the label for the lowest allowed energy state, called the *ground state*. Higher energy states (n = 2, 3, etc) are *excited states*. The separation between energy levels is usually about a few eV's (1 eV = 1 electron-volt = 1.6×10^{-19} J)



Light is emitted from the atom when the atom makes a transition from a higher-energy state to a lower energy state. Light is absorbed by the atom when it makes a transition from a lower-energy state to a higher-energy state.



transition to lower n,
light emitted



light absorbed,
transition to higher n

Isaac Newton (around 1700) believed that light was a particle (like a little pellet) that always travels in straight lines called rays. In 1801, the English scientist Thomas Young performed the famous "double-slit" experiment that showed that light was a wave of some kind. Around 1860, Scottish physicist James Clerk Maxwell developed a theory which showed that light is an electromagnetic wave. So Newton was wrong, right? Actually, he was partially correct.

Quantum mechanics predicts that light is <u>both</u> a wave <u>and</u> a particle. It has both wave-like properties (constructive and destructive interference) and it has particle-like properties. If you look real closely, a beam of light appears to made up of a stream of particles called **photons**. The photon is the smallest possible unit of light. You cannot have an amount of light smaller than one photon. (Yes, this is weird. Einstein was the one who first explained the photon concept, but he was mighty unhappy about it.)

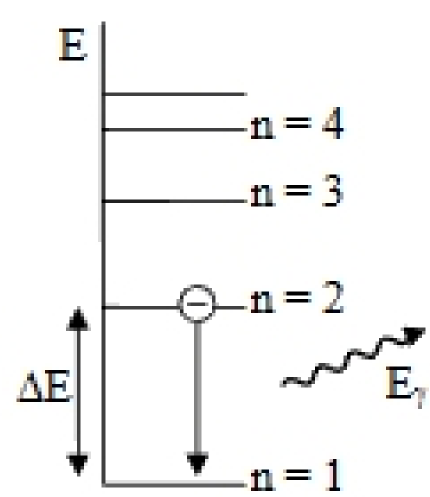
photons are particles of light

The energy of a single photon is given by the formula

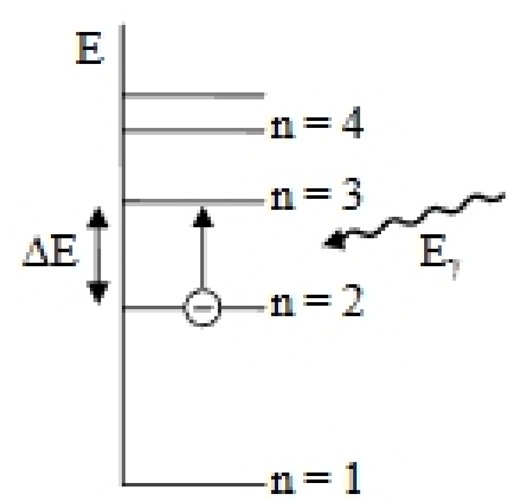
$$E_\gamma = hf = h\frac{c}{\lambda}$$

where f is the frequency of the light and h is a constant, called Planck's constant (after Max Planck, German scientist, c.1900), $h = 6.64 \times 10^{-34}$ J·s. The greek letter gamma (γ) is the symbol traditionally used to indicate a photon, so the energy of a photon is written E_γ. Another useful number to know is hc = 1240 eV·nm; this allows easy conversion between the energy of a photon in eV and its wavelength in nm.

When light is absorbed or emitted by atoms, the light is almost always absorbed or emitted as a <u>single</u> photon. The wavelength of the light is then easily related to the energy difference of the initial and final states of the atom, according to the formula



emission



absorption